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ABSTRACT

A central focus in the study of metacognition is that readers need to recognize what they know about a topic, they need to realize when they have read something they do not understand, and they need to know how to remediate any discrepancies in their understanding. This paper is presented in three sections. The first section discusses what is known from research about teaching students to read scientific text. The discussion includes a review of research reporting on strategies that are effective in helping students read scientific text, research on strategies and other types of metacognitive reading instruction, and research on students' misconceptions about science. The second section provides an assessment of current research efforts involving the interactive-constructive model of reading. The third section suggests topics for future research that can provide insights into teaching students to read and learn from scientific text. Topics that examine the relationships between learners, hands-on science activities, and science reading comprehension include: (1) the relationship between metacognitive strategies and learning science in general; (2) the effects of preconceptions and misconceptions on the comprehension of science and methods of affecting conceptual change in students at all grade levels; (3) the relationship between problem solving in science activities and problem solving in science reading; (4) effective use of text-processing strategies for students at each grade level; (5) Enhancement projects directed toward improving scientific literacy that includes science reading of all types of materials; and (6) comprehension instruction in science. A list (Contains over 50 references.) (MDH)

READING COMPREHENSION AND METACOGNITION IN SCIENCE: STATUS, POTENTIAL AND FUTURE DIRECTIONS

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Introduction

A central focus in the study of metacognition is that readers need to recognize what they know about a topic, they need to realize when they have read something they do not understand, and they need to know how to remediate any discrepancies in their understanding. This paper will discuss what is known from research about teaching students to read scientific text, point out the areas where previous research indicates that more information is needed, provide an assessment of current research efforts, and discuss some ways that future research can provide further insights into teaching students to read and learn from scientific text.

Research Foundations

Sawyer (1991) reported that several variables may influence reading comprehension, specifically, the purpose for reading and the readers' prior knowledge, interest, and ability. She stated that these variables interact with text style, features of the text, and content to produce a dynamic event. She encouraged researchers to utilize content-context specific designs to

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explore comprehension. Along these lines, there has been empirical research studies designed to examine the effectiveness of strategies purported to help students read scientific text. A review and analysis of over 100 studies conducted from 1974 to 1989, reported in sources such as the Journal of Research in Science Teaching, Science Education, The Journal of Reading, Reading Research Quarterly and the Journal of Educational Psychology, suggested that there were at least five instructional strategies that are effective in helping junior high school to university age students read scientific text (DiGisi, 1990). The five strategies are: (1) advance organizers, paragraphs or activities that provide students with some information in advance to help them organize what they are reading (e.g., Ausubel, 1960; West & Fensham, 1976; Mayer & Bromage, 1980; see Table 3. of Digisi, 1990, for complete listing); (2) assessing and addressing students' misconceptions to help them recall information more accurately (Alvermann & Hague, 1989; Hynd & Alvermann, 1989); (3) concept mapping, or teaching students to create maps that illustrate how the ideas in a text are related (Alvermann, 1982; Mhone, 1984; Winn, 1980); (4) teaching students to recognize patterns in how scientific text is written (Cook & Mayer, 1988; Duffy, 1985); and (5) including conceptual questions at the end of a passage (Rothkopf & Bisbicos, 1967; Spring, Sassenrath & Kettelapper, 1986; Mayer, 1980; Watts & Anderson, 1971). These strategies were all shown to be effective in helping students to learn information from scientific text, and more recent studies have continued to explore these strategies in more depth (i.e., Brown, 1992; Holliday & McGuire, 1992; Willerman & MacHarg, 1991).

However, the research on strategies and other types of metacognitive reading instruction indicates that the effectiveness of strategies may vary according to the grade level, the reading level, and the cognitive ability level of the student (Alvermann & Moore, 1991; Haller, Child, & Walberg, 1988; Paris, Wasik, & Turner, 1991). Metacognitive development includes knowing what strategies are available, how they are applied, when they should be applied, and why they help comprehension. Paris, Wasik and Turner (1991) reported that even "12 year olds do not have well-articulated concepts about reading nor fully developed knowledge about effective strategies to enhance comprehension" (p.619). Craig and Yore (1992) and Yore and Craig (1992) found that knowledge about strategic comprehension varies between good and poor readers and that metacognitive knowledge about science reading and science text did not consistently increase with the grade level of the middle school readers. Some metacognitive reading instruction has been effective in improving the reading comprehension of students in the elementary grades. Reciprocal teaching has been effective with students with low reading ability in junior high school and students in first grade (Brown & Palinscar, 1985; Palinscar & Brown, 1984). Teaching students about the structure of expository text has been effective with fifth grade students

(Armbruster, Anderson & Ostertag, 1989). However, the metacognitive strategies in general seem to be most effective for students in seventh grade and older, becoming more effective as students' reading ability and knowledge about reading increases (Haller, Child, & Walberg, 1988).

One possible explanation for why metacognitive reading instruction has not been as effective for students in the fourth, fifth and sixth grades is that fourth grade is when the conceptual demands of reading increase. In school, students are expected to learn new information from books. Therefore, fourth grade students who are able to read narrative stories about familiar topics independently may still have difficulty reading and learning new information from expository text due to the increased cognitive demands of the conceptual information and the unfamiliar nature of expository text (Chall, 1983). Further, research suggests that students are provided with little explicit instruction to bridge the transition between narrative and expository text (Duffy and Roehler, 1989).

An example of how the effectiveness of metacognitive strategies may vary for students in different grade levels can be seen in the research done with students' misconceptions about science. Overall, studies have shown that students with misconceptions about a topic in science hold on to their misconceptions, even after reading a passage that explicitly refutes their prior beliefs (Hynd & Alvermann, 1986). Hynd and Alvermann (1989) found that when college students with misconceptions about Newton's theory of motion were given a simple statement telling them that what they were about to read may differ from what they already know, they tended to recall information from passages more accurately, although they still had difficulty with questions that asked them to apply the theory to situations not discussed in the text. No studies appear to have tested the effects of this type of statement with high school students. However, Brown (1992) provided tenth grade chemistry students with text that included a connected sequence of explanations from concrete situations that were believable to the students (e.g., starting with a hand pressing on a spring, moving toward a flexible board between two sawhorses, and ending with the target example of a book on a table). He found that this type of explanation was effective in helping students to revise misconceptions about Newton's third law, the law of action and reaction (i.e, the students maintained that a table does not exert an upward force on a book resting on it), and to answer post-questions correctly and with confidence. Alvermann and Hynd (1989) found that high school students with misconceptions about Newton's theory of motion who participated in a carefully guided discussion with a researcher and peers after reading a passage, were able to apply the conceptual information from the passage more accurately. However, the discussion did not help the students to accurately answer true/false and short answer questions based on what they had read. Research on elementary students has suggested that younger students (fifth grade and below) are very reluctant to accept statements that differ from their misconceptions and that these students may need to participate in a series of hands-on/minds-on activities before they are willing to accept information that is different from the way they see the world (Anderson & Smith, 1984; Watson & Konicek, 1990). These results illustrate that while the strategy of assessing and addressing students' misconceptions is important at all levels, the type of instruction needed varies greatly according to the grade level of the student.

In addition to grade level, the effectiveness of metacognitive strategies appears to vary with reading ability level and cognitive ability level in terms of the students' development and experience of the world (Haller, Child & Walberg, 1988; Jacobs & Paris, 1987; Paris, Wasik & Turner, 1991). Some strategies (for example, concept maps) have been shown to be more effective with students with high ability than students with low ability at the same grade level, whereas students with low ability seem to benefit more from instruction in self-questioning (Alvermann & Moore, 1991). The majority of research on metacognitive strategy instruction has been limited to a very short time period (for example, 10 minutes per lesson for 6 weeks). Therefore, it has been suggested that students of high ability and older students may need only a minimum of instruction to develop metacognitive awareness or to understand how strategies can be helpful in comprehending text (Alvermann and Moore, 1991). However, students with low abilities and sparse language experiences may need more explicit instruction and more time to practice using metacognitive strategies before they are able to use them independently (Duffy & Roehler, 1989).

In cases where strategy instruction has been effective, teachers have used scaffolding or coaching to carefully move students from the point where they are directed by the teacher to the point where they take control of their own learning (Roehler & Duffy, 1991). Teachers accomplish this through gradually reducing directions and questions until students are able to regulate their own learning. Pearson and Dole (1987) suggested that explicit comprehension instruction should establish a need-to-know, model the desired outcome, provide directed practice and strategy consideration, facilitate the transfer of ownership to the student, and provide opportunities to apply the strategies in other situations. Palinscar and Brown (1986) utilized a reciprocal peer-teaching approach to guide practice, transfer, and application of strategies. Fields (1990) provided the following guidelines for strategic instruction: (1) embed instruction in real tasks, (2) explain and model problem-solving aspects of strategic reading, (3) utilize think-alouds (where the teachers model their thought processes out loud as they solve a comprehension problem or approach a comprehension task), and (4) encourage students to use similar approaches. Duffy and Roehler (1989) suggested that teachers need to explicitly inform students, particularly students with low ability or poor reading skills, that:

> (a) they should be in conscious control of the strategy they are being taught, and (b) that they need to recognize situations where the strategy will be needed and search their mental repertoire of strategies to access an appropriate one. (p. 147)

In sum, the research results suggest that explicit instruction should provide declarative (WHAT), procedural (HOW), and conditional (WHEN and WHY) knowledge about strategies and how students should manage and utilize the strategies they know.

Current Research

The interactive-constructive model of reading is a model of reading which suggests that readers use metacognition to control the process of learning from text by actively integrating information in the text with their prior knowledge and utilizing comprehension strategies to construct new meaning from the text as they read. The interactive-constructive model of reading, metacognition, and comprehension strategies are the central perspective of many current research projects in science. Several studies reported in current issues of science education journals have explored the interactive effects of questions in text (Holliday & McGuire, 1992; Pizzini, Shepardson & Abell, 1992), inquiry learning with supplemental text (Barman, 1992), textbook logic and treatment of evidence (Stinner, 1992), and textbook usage in biology classrooms (Gottfried & Kyle, 1992). Each of these studies used an interactive-constructive framework, but Holliday and McGuire (1992) explicitly explored the potential of infusing strategies and metacognitive perspectives into the design of the study and the discussion of the results. Their study was designed to build on the results of traditional studies that examine the effects of adjunct questions, and incorporated a procedure to examine the effects of "descaffolding" or reducing the amount of guidance students were given by including a group of students that received a partial set of adjunct questions as well as a group that received the full set of adjunct questions.

Craig and Yore (1992) and Yore and Craig (1992) found it necessary to direct their inquiries at the basic foundation of reading comprehension in science. They found little research evidence on science reading and little evidence to support that research with narrative and expository writing in other subject areas would apply to comprehension issues dealing with scientific textual materials. As a test model for their research, they used a desired image of an effective science reader, based on research on comprehension of expository text and an analysis of scientific textual demands (Yore & Denning, 1989). Their current research confirmed that metacognition is difficult to define, knowledge about strategic comprehension varies between poor and good readers, and metacognitive knowledge about science reading and science text does not consistently increase with the grade level of the readers. Yore and Shymansky (1991) identified several strategies that may be used in explicit metacognitive reading instruction and could be tested empirically for their effectiveness with students reading scientific text. These current research efforts have begun to explore using metacognitive planning, monitoring, and regulating strategies as well as declarative, procedural, and conditional knowledge about science reading and science text.

Future Directions

In light of what is known about metacognitive comprehension instruction, two questions require further exploration: (1) what type of metacognitive instruction is appropriate for science students at each grade level, reading level, and level of cognitive ability, and (2) how much instructional time and practice with metacognitive reading strategies is needed for students at each grade level. Current research has examined metacognitive reading instruction in laboratory and small group situations, where students have used specially prepared texts, and they have been instructed over a short period of time by a researcher well versed in the theory and practice of instruction in metacognitive strategies. Future studies need to examine the effects of this instruction within the constraints of the natural classroom environment, where classroom teachers with reasonable training and experience with comprehension strategies instruct students using regular classroom textbooks and materials. For example, studies that examine actual classrooms where metacognitive reading instruction is integrated into the science instruction will provide valuable information about the realities of using metacognitive strategies in ecologically valid settings. Currently, there are few studies that include interviews with both teachers and students, and classroom observations where teachers' instructional actions are documented and referenced to actual lesson excerpts. This type of research, where both teachers' and students' thought processes are revealed through interviews and classroom discourse and are linked to science achievement, will provide deeper insights into learning and teaching metacognitive reading strategies and their relationship to comprehension.

The need to examine how science teachers instruct students in metacognitive reading strategies within their classroom settings and with their own curricular materials, requires a related examination of how science teachers are instructed to incorporate metacognitive reading strategies into their science instruction. Evidence from large scale surveys of content area teachers in general, and science teachers in particular, indicates that secondary teachers value the importance of reading instruction in science, and have positive attitudes about enrolling in content area reading courses (Gillespie & Rasinski, 1989; Yore, 1991). However, teachers have reported that their lack of knowledge about how to integrate reading into their instruction and the pressure to cover content due to curricular guidelines or regional exams, inhibits their practices of integrating reading into their science instruction (Gillespie & Rasinski, 1989; Shymansky, Yore & Good, 1991; Yore, 1991). This difficulty is illustrated in the results of a longitudinal study conducted by Hollingsworth and Teel (1991). This study monitored one science and one math pre-service teacher starting from their entry into a required content-area reading course and through their first two years of teaching. Hollingsworth and Teel found that both teachers indicated that they had learned the content of the reading course and had attempted to integrate reading instruction into their student teaching. However, the lack of support and role models in their teaching placements, and the curricular and classroom management constraints placed on them as new teachers, inhibited their incorporation of the reading strategies into their math and science teaching practice.

These research results indicate that further examination of the type of reading instruction that will help science teachers work within the constraints of their classrooms is needed. Currently, the majority of content area reading courses provide a quick overview of reading and speak about general strategies for helping students to read content area subjects. Since few courses discuss strategies that have been shown to be effective in specific content areas such as science (DiGisi, 1990) and social studies (Wade, 1983), the effect of a course specifically tailored to science teachers' needs is not known. Another area to be examined is how much and what type of instruction current science teachers and pre-service teachers would need in order to comfortably integrate reading strategies into their science instruction. Previous research has suggested that the current model of a general overview of content area reading is not effective. It appears that teachers need to incorporate what they learn into their classroom instruction and then return to the reading or methods class to discuss their experiences and receive feedback from the instructor and their peers (Hollingsworth & Teel, 1991; Yore & Shymansky, 1991). Clearly, there is a need to examine the practices of teachers who are able to integrate methods of metacognitive reading instruction into their science instruction and to learn more about the kind of reading instruction that will most benefit pre-service and practicing teachers.

In addition to teacher education, researchers need to examine the instructional materials for science that are currently in use. Current materials do not provide teachers with substantive assistance toward instructing students how to learn from reading (DiGisi, 1990; Duffy & Roehler, 1989). A survey of pupil texts and teacher's guides in the ten most frequently used biology textbooks in the Boston area found that publishers consistently provide a great deal of reading support in the student texts, such as printing new vocabulary in bold print and including questions at the end of the chapter; but, they provide teachers with very little instruction and guidance in how to help students learn from reading their textbooks (DiGisi, 1990). Some reading strategies were recommended to teachers, such as setting a purpose for reading and teaching students to create concept maps, but the recommendations varied from publisher to publisher and were not consistent with strategies for helping students to read scientific text recommended by research. Preliminary responses to a large scale survey of biology teachers in the New England area suggests that teachers are anxious to know more about instructional strategies and techniques to help students learn from reading, particularly since budget cuts have eliminated the reading specialist in many school systems (DiGisi, in progress). More needs to be known about how teachers use textbooks and teacher's guides in their instruction, and where they turn for help in instructing students how to learn from their textbooks.

Further, research is also needed to establish relationships between teaching students to monitor and manage what they have learned from reading and science learning in general. Numerous issues that examine the relationships between learners, hands-on/minds-on science activities, and science reading comprehension stand ready for further research, such as:

1. The relationship between metacognitive strategies and learning science in general.
2. The effects of preconceptions and misconceptions on the comprehension of science and methods of affecting conceptual change in students at all grade levels.
3. The relationship between problem solving in science activities and problem solving in science reading.
4. Effective use of text-processing strategies for students at each grade level in the science classroom.
5. Enhancement projects directed toward improving scientific literacy that includes science reading of all types of

materials (i.e., biographies, magazine articles, journal articles, textbooks).

6. Comprehension instruction in science.

Fundamental questions regarding the relationship between metacognitive knowledge about science reading and science text, self-management of strategic action, and the construction of science understandings must receive high priority. Many misconceptions about science reading and science learning are based on lack of evidence about how readers actually make meaning from print. Currently, science textbooks are more frequently misused than used in ways that promote learners to take in new information and relate it to their prior knowledge. Students receive little explicit instruction in reading science and have few opportunities to determine for themselves how the "enormous, impressive, and extremely useful collection of facts, principles, and concepts which, because of the way it brings order to the world is both intellectually satisfying and practically useful" (Newton, 1968, p. 809).

Summary

Whether teachers turn to reading education courses, the teachers' editions of their textbooks, or professional journals, it is clear that there is a need to know more about how to improve instruction of metacognitive reading strategies within the context of the science classroom. Research must establish reliable relationships between metacognition, comprehension strategies, and learning; identify the best types of instruction for students at each grade and ability level; and determine how much instruction is needed for students at each grade level. Including metacognitive reading instruction into the natural classroom setting with current expository text materials, and instructing science teachers to effectively integrate reading to learn science with laboratory work and other hands-on/minds-on experiences must become an integral part of teaching methods in science (Romance & Vitale, in press). Teaching students to effectively read and learn from scientific text is important to ensure that students leave the classroom knowing the science content they were taught, and with the tools to continue learning science in the future, thus providing an ongoing and regenerating dimension to scientific literacy.

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